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Tristeza Disease of Citrus, with Special Reference to Its Situation in the United States

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THE virus that causes the tristeza or quick decline disease of citrus is known to be present in North America (13, 43), South America (3, 22), South Africa (20,21, 24), West Africa (1, 18), Hawaii (15), Australia and New Zealand (8, 19), and Israel (45). Diseases of citrus which appear to be the same as tristeza have been reported from Java (39), Ceylon (29, 30) and the Fiji Islands (2).

Tristeza causes greatest losses to citrus trees of certain scion-stock combinations, notably those of sweet orange (*Citrus sinensis*) budded on sour orange (*C. aurantium*) and some other rootstocks. It has been particularly destructive to the citrus plantings in South America and California.

History and the Cause

The effects of the tristeza disease were apparently known before the present century. However, it was not until it appeared and caused heavy losses in Argentina and Brazil in the 1930's that it was recognized as a distinct disease. Prior to the outbreaks in South America no extensive efforts had been made to determine its nature nor to find means for its control.

In the late 1890's the citrus industry in South Africa began the use of sour orange as a rootstock and it was soon observed that sweet orange and mandarin (*Citrus reticulata*) trees budded on sour orange rootstock usually died within two or three years. With that experience and with the knowledge that sweet orange and mandarin grew satisfactorily on Rough lemon (*C. limon*), their propagation on sour orange was discontinued and Rough lemon was used as a rootstock almost exclusively thereafter. During that time it was also noted that lemon trees on sour orange grew well and produced profitably.

For many years the failure of sweet orange trees on sour orange rootstock in South Africa was attributed to an incompatibility between sour orange and certain scion varieties. After a visit to South Africa, Webber (46) pointed out that trees of both Washington Navel and Valencia oranges on a given strain of sour orange rootstock developed normally in California and other parts of the world. Although the same combinations failed in South Africa, Webber concluded: "it is inconceivable that all sour orange strains would be incompatible or uncongenial with sweet orange."

In 1928 a disorder affecting trees of sweet orange, tangerine, and grapefruit (*Citrus paradisi*), grown on sour orange rootstock was noted in Java. Toxopeus (39) suggested that the disease was the same or similar to that observed earlier in South Africa. In 1930 or 1931 what appeared to be the same disease was observed in Argentina where it was given the name "podredumbre de la raicilla" (4, 9). After its appearance in Brazil in about 1937 (5), the disease became generally known in South America by the name "tristeza." In those South American countries the disease spread rapidly through citrus plantings and caused disastrous losses.

It is now known that "quick decline" caused the death of a few trees in California as early as 1939. It was not until 1942 however that it was suspected of being the same as tristeza. Because one half or more of the citrus acreage in California was then on sour orange rootstock, the potential losses were great. Consequently an intensive research program was quickly developed in an attempt to learn the nature of the disease and to find possible control or preventive measures. From experimental transmission studies Fawcett and Wallace (13, 43) in 1946 demonstrated that quick decline was caused by a virus. Simultaneously, Meneghini (22) reported that tristeza in Brazil was also a virus disease and the virus was transmitted by the citrus aphid, *Aphis (Toxoptera) citricidus* Kirk.

Following these discoveries, investigations in West Africa (18), South Africa (20, 21), Brazil (10), United States (7, 40, 41), and Argentina (12) have shown that the tristeza virus is not only responsible for a disease of sweet orange, mandarin and grapefruit on sour orange and certain other rootstocks, but that the same or related strains of the virus also cause such diseases as stem-pitting of grapefruit in South Africa and the lime disease in the Gold Coast.

Economic Importance

Actual losses resulting from tristeza in various countries where it exists have not been reported in recent years. The most serious damage occurred generally in the citrus regions of Argentina and Brazil and in localized areas of California. An example of the devastating losses is cited by Bennett and

Figure 1. Sweet orange on sour orange rootstock in the collapse stage of tristeza infection. At the right, a normal tree.

Costa (3) who stated in 1949 that within 12 years after the disease appeared in the State of Sao Paulo, Brazil, 6,000,000 trees or about 75 percent of the orange trees of the State had been destroyed.

In South Africa, inasmuch as sweet orange varieties have been grown almost exclusively on Rough lemon rootstock these have not been seriously damaged by the disease. On the other hand, grapefruit trees have suffered from a decline caused by the stem-pitting phase of tristeza. Oberholzer *et al* (25) reported in 1949 that in plantings of Marsh Seedless in South Africa from 30 to 90 percent of the trees were fairly severely affected. Yield studies in South Africa have shown that severely affected grapefruit trees produced very little fruit of commercial value.

Hughes and Lister (18) reported that seedling lime (*Citrus aurantifolia*) trees were killed by the lime disease to the extent of threatening the loss of the lime industry in the Gold Coast.

There are no records available concerning the total losses from tristeza in the citrus plantings of California. The disease has not yet invaded some of the important citrus-growing areas, but once it becomes established in groves of sweet orange on sour orange rootstock there is a gradual spread and in some locations all trees become worthless within 10 years or less. Since the disease was first observed in California in 1939, almost 300,000 trees are known to have been destroyed or made worthless. The actual number may amount to nearly 400,000, since surveys do not reveal all of the diseased trees and many have been removed by the grower without the knowledge of county or state officials.

Symptoms

Collapse and decline of budded citrus trees. The symptoms originally described for "podredumbre de la raicilla" in Argentina, "tristeza" in Brazil, and "quick decline" in California were those of affected trees of sweet orange varieties growing on sour orange rootstocks. The reaction of such susceptible trees after infection may follow one of two patterns. The most striking reaction is the sudden wilting and drying of all of the leaves (Figure 1). In California young trees under

Figure 2. Valencia orange tree in advanced stage of tristeza. Such trees may die but sometimes may survive in a weakened condition.

5 or 6 years of age commonly react in this manner and many such trees fail to survive (Figure 2). On such trees most of the feeder rootlets and some of the lateral roots become decayed. Frequently the trunk of the tree shows no stored starch in the part below the bud union nor in the roots (Figure 3). Other trees which appear to be dying will sometimes partially recover and remain alive indefinitely after complete defoliation and some die-back of smaller twigs and limbs. After recovery begins, some starch reappears in the roots and there is new root growth but the trees never return to a normal condition.

Older trees sometimes also collapse quickly but they too, for the most part, make some recovery eventually. The first symptoms to be noticed on old trees are a bronzing or yellowing of foliage, gradual loss of leaves

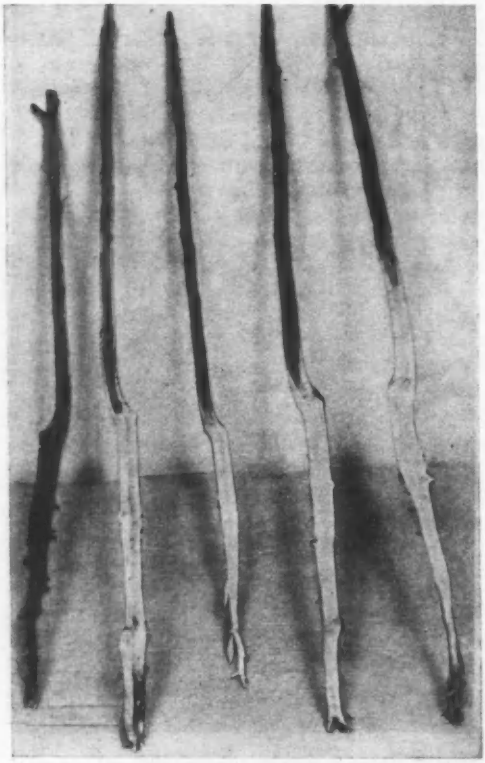

Figure 3. Starch distribution in healthy and tristeza-infected trees of sweet orange on sour orange rootstock. Trees sectioned longitudinally and treated with IKI solution. Left, healthy tree; right, four trees in various stages of tristeza infection. (Photo by L. J. Klotz.)

and premature coloring of fruit. Often such trees bear an abnormally heavy crop of fruit which is usually somewhat smaller in size than the fruit on unaffected trees.

The most conspicuous symptom on young trees in the early stages of infection is the tendency to blossom heavily and to set and mature fruits (Figure 4). Healthy trees of comparable age blossom much less and fail to hold any fruit which they may produce.

Schneider (31, 32, 35) and Schneider *et al* (36, 38) have shown that in quick decline or tristeza-infected trees the phloem in the bark in the region of the bud union becomes necrotic. In effect, the necrosis induces a girdling which prevents the movement of food to the roots. This results in the utilization of the reserve food of the root system and subsequent root decay. In trees that make some recovery, phloem is regenerated somewhat faster than it becomes necrotic and the trees remain alive in a state of reduced vigor. Sieve tube necrosis is associated with several diseases or disorders of citrus (33, 37) but in tristeza-affected trees there are also certain other characteristics and specific anatomic changes which can be used for diagnosis.

The incubation period of the disease in old established trees is not known, but in trees 1 to 2 years old from time of budding symptoms sometimes appear within 4 to 6 months after infection. On such trees the first symptoms to appear are early and heavy blossoming, slight dull color of leaves and reduced new shoot growth.

Stem-pitting. It is now known that both seedling and budded citrus trees of many

Figure 4. Tristeza-infected young Valencia orange tree. Setting and maturing of fruits and the heavy off-season flowering characterize such trees particularly during the first year after they become infected.

different varieties develop " stem-pitting " as a result of infection with the tristeza virus. The causal relationship was first demonstrated by Hughes and Lister (18). Following their report that seedlings of lime develop pitting when infected with tristeza virus, similar results were obtained in Brazil, South Africa, and California.

Stem-pitting in citrus is of varying types (12, 16) and sometimes it is caused by viruses or factors other than the tristeza virus. For instance, citrus trees on rootstocks of Palestine sweet lime almost always develop stem-pitting. This disorder was described by Reichert and Perlberger (28) and is known as xyloporosis. It has not yet been demonstrated to be infectious and its cause remains unknown.

In California and Arizona the writer has observed pitting of various types on citrus trees which were not infected with tristeza virus. Whether or not other unknown viruses were present was not determined. Even though tristeza virus is present in field grown trees which display stem-pitting one cannot ascribe the symptoms with certainty to tristeza. In other words, as mentioned by DuCharme and Knorr (12), virus mixtures or other causes may be involved and therefore it is not possible to identify specific kinds of stem-pitting on field trees as being caused by tristeza virus. Any budded citrus tree may carry in addition to tristeza virus other viruses or factors which induce pitting. Likewise, citrus seedlings exposed to natural infection by insects may harbor more than one virus. The degree, location and kind of pitting are undoubtedly influenced by the citrus seedling variety or the particular combination of scion and rootstock varieties.

In California a considerable range in degree and type of pitting has been observed on lime seedlings infected with tristeza virus by insect inoculation and kept free of infection by other viruses. On young seedlings of sour lime (Mexican or West Indian) the pits consist most commonly of longitudinal grooves or depressions paralleling the grain of the wood (Figure 5). Corresponding and fitting into the depressions in the wood are protuberances on the inner face of the bark. When the pits are numerous they coalesce to form larger depressions and as the trees become older the pitting can be observed externally without removal of the bark. At times pits similar to those described by DuCharme and Knorr as " channeling, " " deltoid ", and " fluting " are also present.

Figure 5. Mexican lime seedling experimentally infected with the tristeza virus, showing pitting in wood.

The reduction in vigor of grapefruit trees as known in South Africa and shown in preliminary observations in the tristeza rootstock trials now in progress in California (6), gives evidence that certain citrus varieties which are not subject to the decline or collapse symptoms, when grown as seedlings or on " tolerant " rootstocks, may suffer injury from the stem-pitting manifestation of tristeza. The original belief that the use of varietal combinations of scion and rootstock which are not subject to phloem necrosis at the bud union will provide a solution for the tristeza problem is no longer tenable.

Thus it is clear that the control or prevention of damage from tristeza is much more difficult than it was first assumed to be.

Insect Vectors

It has been established in recent years that the principal insect vector of the tristeza virus in South and West Africa, Australia, and several countries of South America is the citrus aphid, *Aphis citricidus*. This species is not found in the United States or the Mediterranean area. It has been shown experimentally to be an efficient vector, infections sometimes resulting from the feeding of a single insect (3).

In California (11) and Florida (23) it was demonstrated that the melon aphid, *Aphis gossypii* Glover, is capable of transmitting the virus, but the efficiency of this species is much less than that reported elsewhere for *A. citricidus*. Transmission was also obtained experimentally in Florida with the spirea aphid, *A. spiraecola* Patch, but with only low percentages of infection. Studies in California, however, failed to demonstrate that *A. spiraecola* and numerous other species of aphids tested could transmit the tristeza virus.

Dickson *et al* (11) state: "The melon aphid breeds on citrus and a long list of other plants. It is the second most widespread aphid on earth, so it will be found on citrus trees at least occasionally wherever they are grown. On citrus it lives only on the young leaves and buds. While the melon aphid has a considerable range of color (dark gray, tan, greenish, pale yellow) on some of its host plants, it is almost always dark gray when growing on citrus. In the field it may easily be confused with the black citrus aphid (*Toxoptera aurantii* [Fonsc.]), the cowpea aphid (*Aphis medicaginis* Koch.) and the bean aphid (*A. fabae* Scop.)."

In the Gold Coast, Hughes (17) recently reported that the virus causing the lime disease was transmitted experimentally by a mealy bug, *Ferrisia virgata* Ckll., but the results seem to need further verification.

Origin of the Disease

It has been suggested that tristeza might have originated in South Africa and later spread to other parts of the world in budwood or trees which are symptomless hosts of the virus. Wallace *et al* (44) are of the opinion that although the tristeza virus became established in South America following the importation of citrus nursery trees from South Africa, studies in California (42, 44) and Texas (26, 27) indicate strongly that the virus is of oriental origin and that it reached the United States and some other countries in citrus trees or propagative material which came either directly or indirectly from China and Japan. The common occurrence of the virus in progeny trees of Meyer lemon which was brought into the United States in 1908 from China and in numerous satsuma orange varieties which came from the Orient even earlier suggests that the virus was present in the United States long before it was discovered in sweet orange varieties.

Studies in California also indicate that the tristeza virus was very probably brought into the United States repeatedly in numerous citrus importations. Except for one importation from South Africa the known introductions of the virus were by means of citrus trees or budwood which came directly or indirectly from China or Japan. In addition, some existing propagations from material introduced from Australia, Hawaii and the Philippine Islands as early as 1914 are carriers of the virus. These trees, and in some cases propagations from them, were found to be diseased in an area where only a trace of natural infection has occurred in adjacent susceptible trees of sweet orange on sour orange rootstock. It appears that the virus was carried in the original importations.

The finding that numerous varieties of satsuma orange growing in a variety collection in Texas (26) are carriers of the virus, while adjacent trees of other susceptible citrus are not infected, suggests that the virus was probably brought into the United States as early as the 1880's. During that time thousands of satsuma trees were imported from China and Japan for planting in the Gulf States of the Southern United States. If the virus was generally present at that time in China and Japan it seems certain that some of the trees imported into the United States would have been infected.

The feeding habits of *Aphis gossypii* and its inefficiency in transmission can explain

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how the virus could be present in certain citrus hosts in the United States for a long period before becoming established to any noticeable extent in more susceptible types of citrus. On the other hand, where *Aphis citricidus* was present in abundance, as in South Africa and South America, rapid spread of the virus would have been expected shortly after the virus was introduced. In South Africa the virus was probably widely distributed in seedling trees and trees budded on the tolerant Rough lemon rootstock, before attempts were made to use sour orange as a rootstock which brought the disease into evidence. The situation differed in South America in that approximately 75 percent of the established citrus consisted of trees budded on susceptible rootstocks. With an efficient insect vector present, the tristeza disease became an immediate threat and serious losses soon resulted.

Varietal Susceptibility

Budded trees of certain scion-stock combinations such as sweet orange on sweet orange rootstock (14) and seedling trees of most commercial citrus varieties are highly resistant to injury from tristeza, although probably all are susceptible to infection. Sour lime is perhaps the only commercial variety known to show appreciable injury when seedling trees are infected naturally or experimentally. Seedlings of some other species or varieties become yellowed and stunted if they are infected when very small, and it is known that others are subject to stem-pitting. For the most part, however, experimentally infected seedlings have not been studied sufficiently to learn what the ultimate effects of stem-pitting will be.

Inasmuch as most of the world's citrus now consists of budded trees of certain scion-stock combinations, tristeza has caused its greatest damage to such trees. The most serious ravages of the disease have occurred in plantings of sweet orange on sour orange rootstock. Grapefruit and tangerine on sour orange probably rank second and third in susceptibility. Sweet orange and tangerine when growing on grapefruit rootstock are also subject to injury, but their rate of decline is somewhat slower than that of trees on sour orange rootstock. The current rootstock investigations in California and Brazil will undoubtedly add much to our knowledge of scion-stock reaction to tristeza. However, they must be continued for a longer period in order to find scion-stock combinations that not only are resistant to the phloem necrosis of the bud-union tissues, but are also not subject to injury from the stem-pitting phase of the disease.

In the established plantings in Southern California where nearly all of the sweet orange trees on sour orange rootstock have been destroyed by tristeza, sweet orange trees or sweet orange, Rough lemon and trifoliate orange (*Poncirus trifoliata*) have shown no evidence of injury. Grapefruit on these same three rootstocks also appears to be tolerant. Although no plantings of grapefruit on grapefruit rootstock have been available for study within the tristeza-affected area of California, it is assumed from other studies that this would also prove to be a tristeza-tolerant combination. Eureka and Lisbon lemons on sweet orange and sour orange rootstocks appear to be unaffected by tristeza.

In California trials Troyer citrange (*Poncirus trifoliata* x *Citrus sinensis*) and Cleopatra mandarin show promise of being satisfactory rootstocks for sweet orange from the standpoint of tristeza. However, Troyer citrange like trifoliate orange, may prove to be subject to exocortis which is now believed to be caused by a virus quite generally distributed in citrus. Other virus or virus-like diseases such as cachexia, xyloporosis, and the Rangpur lime disease must also be taken into consideration in evaluating new rootstocks. Thus it becomes clear that the selection of new rootstocks for citrus is no longer a matter of finding resistance to a single disease in an otherwise horticulturally suitable rootstock.

Diagnosis of Infected Trees

It is not possible to diagnose with certainty for tristeza on the basis of tree condition except in the case of sour lime and some uncommon types of citrus which display characteristic leaf symptoms when infected. The symptoms associated with either rapid collapse or the slow decline of citrus trees from tristeza infection are identical with those which follow severe root damage from

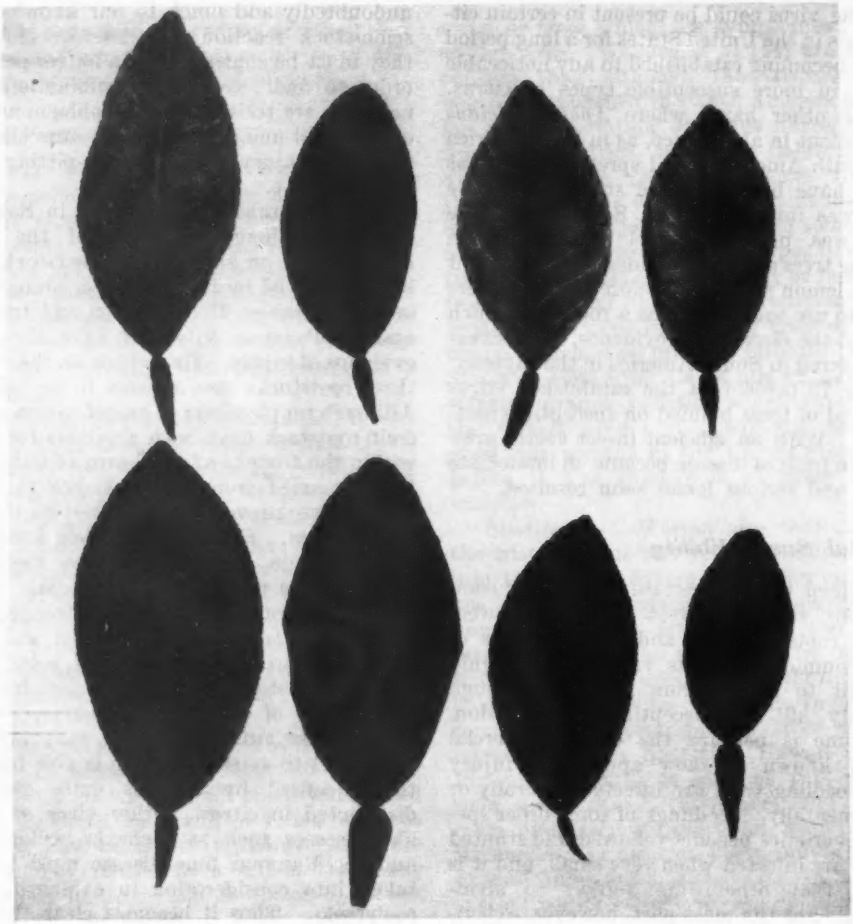

Figure. 6. Symptoms of tristeza on leaves of Mexican lime. Upper, characteristic clearing of veins and veinlets on leaves from diseased plants. Lower, leaves from normal plant.

other causes. If an orchard tree is suspected of having tristeza the following examination should be made:

1. Determine the rootstock variety, if possible.
2. Cut into wood across bud-union and make test for starch by applying iodine (IKI) solution. Starch above union but not below indicates phloem necrosis from tristeza or some other cause.
3. Examine root system for sloughing of fiber roots and rotting of small roots, and test small roots for starch.
4. Examine underground portion of trunk and tap root for rodent injury, gummosis or other disorders.
5. Eliminate other possible causes of root damage such as overwatering or excessive fertilizing.

If the suspected tree is known or thought to be a scion-rootstock combination susceptible to tristeza, and its diseased condition

cannot be attributed to other causes, two additional tests may be made. One of these, the anatomical test described by Schneider (34) can be completed in a short time by one who has sufficient experience in the identification of anatomical effects of tristeza, if laboratory facilities and equipment are available.

An easier method of diagnosis, but one which requires a longer time, is the inoculation or transmission test. Small twigs or buds are cut from the suspected tree and grafted to sour lime seedlings. If the study is being made where tristeza is known to be present the lime seedlings must be grown under insect-free conditions to avoid natural infection. In California (40, 41) lime seedlings well established after transplanting into pots from the seed bed are sometimes inoculated when they are no more than 4 or 5 inches in height, but the grafts are easier to make if the seedlings are somewhat larger. If the tristeza virus is transmitted the newly formed leaves of the lime plants will show vein-clearing (Figure 6). Frequently the new leaves that develop after infection takes place are dwarfed, chlorotic and slightly cupped or boat-shaped. Even on the chlorotic leaves early stages of vein-clearing can be detected if the leaves are examined against a source of light. Under glasshouse conditions the leaf symptoms usually begin to appear within 4 to 5 weeks after inoculation.

In the lime test it is necessary to distinguish between the symptoms of psorosis and tristeza because psorosis may be present either alone or in combination with tristeza. The vein clearing due to tristeza is much more distinct and is more limited to the veins. The symptoms are persistent and are often present on old leaves. On the other hand psorosis may cause blotchy patterns, less clearing of veins but broader streaks which ordinarily disappear as the leaves mature. In case there is difficulty in diagnosis on the basis of leaf symptoms, the lime seedlings should be examined for stem-pitting about eight weeks after inoculation by peeling back strips of bark on the main stem or cutting off twigs and removing the bark. In California, Mexican or West Indian lime seedlings are used for this test, and to date no virus other than the tristeza virus has induced stem-pitting. It should be mentioned that in growing lime seedlings for tristeza studies, all off-type, vigorous, large-leaved seedlings should be eliminated as they do not express good symptoms.

The rate of appearance and degree of stem-pitting on lime seedlings vary between individual plants and very probably are also influenced by different virus strains. These facts should be understood when the lime test is used for the detection of the tristeza infection.

Control Measures

Control measures for tristeza have been studied from two standpoints: 1) the saving of existing plantings of susceptible scion-stock combinations, and 2) avoiding losses in new citrus plantings.

In California, the greatest success in salvaging plantings of sweet orange on sour orange rootstock in the tristeza-affected area has been attained by top-working the orange trees to lemon. Numerous factors, particularly environment, influence the success of changing the trees over to lemon (3, 7, 37).

Some success has resulted from inarching, that is, changing existing trees over to resistant rootstocks. Whether or not such a practice is successful depends on many factors. In California (7), because of the high cost of inarching and the long time required to establish the inarched rootstocks it is more satisfactory and economical to remove susceptible trees after they become infected and to replant with a resistant combination. In other places, where labor costs are less and where the disease is developing slowly, however, it may prove advisable to inarch before the disease appears. Threatened plantings could thus be established on resistant stocks by the time they become exposed to infection.

Avoiding losses in new citrus plantings depends mainly on the use of tolerant scion-stock combinations. At present it is advised that rootstocks of sweet orange, Rough lemon, Cleopatra mandarin and Troyer citrange be used. Trifoliate orange is acceptable as a rootstock if the scion varieties budded onto it are free of the exocortis virus. Rangpur lime, which as a stock is tolerant to tristeza, is objectionable because of its suscep-

tibility to the Rangpur lime disease and possible other disorders.

The rootstock investigations currently in progress in Brazil and the United States will probably provide additional tolerant rootstocks for future use.

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Tristeza and Stem-pitting Diseases of Citrus in South Africa

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TRISTEZA was first reported from South America as a disease of citrus trees on sour orange stocks. Work in Brazil, and notably that of Bennet and Costa (1), demonstrated that the disease was caused by a virus, which could be transmitted either by grafting or by the insect, *Aphis citricidus* Kirk. The virus is interesting because when transmitted to many species of citrus growing either on their own roots or on certain tolerant rootstocks, such as Rough lemons or sweet oranges, the infection that results is a latent one without producing visible signs of disease; and the severe effect of tristeza disease is produced in tolerant species only when they are grown on non-tolerant stocks, of which the most important is the sour orange. The harmful effect of the disease, although seen in the behavior of the scion is due to a destructive action of the virus in the conducting tissue of the stock, mainly in the region immediately below the bud union. This partially severs communication between stock and scion with harmful results to the tree as a whole. New flushes of growth are either partially or completely suppressed, the old leaves gradually turn yellow and fall from the trees, branches die from the tips, and ultimately the changes may be followed by the premature death of the tree as a whole.

From the work of Grant and Costa (3) much valuable information is now available on the behavior of different scion-stock combinations to infection under the conditions in Brazil.

In South Africa, and probably in neighboring territories as well, tristeza virus has been present for a long time. Attempts to use the sour orange as a stock for sweet oranges, tangerines, and grapefruits have failed repeatedly over the years. This was put down to incompatibility, and the first proof that it was a virus problem linked with tristeza disease was given by Oberholzer (7). From the evidence of the incompatibility between sweet orange and sour orange there is no doubt that a virus with the same properties as the tristeza virus of Brazil has existed in South Africa almost as long as the citrus industry itself.

The country of origin of the virus has caused speculation. But all that can be said with certainty is that the virus was already present in Africa, Australia and the Far East before its transfer to the Americas in importations of infected trees.

Effects of Tristeza and Stem-pitting

Sweet oranges. The citrus industry in South Africa has virtually grown up with virus infection, and from experimental evidence it is now accepted that all orchard trees carry infection.

As far as is known this has not had any obvious adverse influence on the growing of sweet oranges, and the industry over the years has maintained a good standard of productivity and remained commercially sound. This is due to the use of Rough lemon as the root-stock and to the tolerance possessed both by the Rough lemon and the two main commercial varieties of sweet orange (Valencia and Washington Navel). Young trees grow well and apparently are unaffected; but it is possible that harmful effects ultimately occur in the aging tree with a shortening of its productive life. There is evidence for this in a tendency for orange trees to decline prematurely after 25 to 30 years. Neither Rough lemons nor sweet oranges are completely devoid of symptoms, and a mild form of wood pitting is common in many trees; and in some varieties of oranges being grown experimentally wood-pitting is extensive.

Grapefruit. Grapefruit in South Africa has for many years shown a tendency to decline early. Attention was first drawn to the decline by Oberholzer *et al* (8), who described the condition as stem-pitting and suggested that it might be caused by virus infection. The virus nature of the disease was subsequently confirmed by McClean (4), who also established that the infection associated with diseased trees bore a relationship to the infection that occurred generally in orchard trees. The important primary symptom of stem-pitting is revealed by stripping off the bark from the stems. The underlying wood shows distinctive lesions in the form of pits and shallow grooves and on the inner surface of the bark are projections which fit snugly into the depressions in the wood. The lesions are particularly well defined and numerous in the trunk and larger branches (Figure 1). As affected trees become older they tend more and more to show visible signs of harm, and the secondary symptoms associated with this phase resemble closely those described for tristeza disease. The yield of fruit on declining trees progressively decreases, and the fruits themselves are predominantly of small size and of little commercial value.

Trees decline on both Rough lemon and sweet orange stocks (Figure 2), and the disease is not one necessarily associated with trees on intolerant stocks. The injury to trees and their subsequent decline is due probably to the sensitivity of the grapefruit scion itself.

Although all orchard trees of grapefruit are infected with virus, many trees are to be seen that are still in good condition and continue to produce good crops, some even after 25 years. From one such tree a milder strain of virus was isolated, but it is by no means certain that the continued good performance of trees is due to infection by a milder strain. This still requires investigation.

A disease similar to stem-pitting in grape-

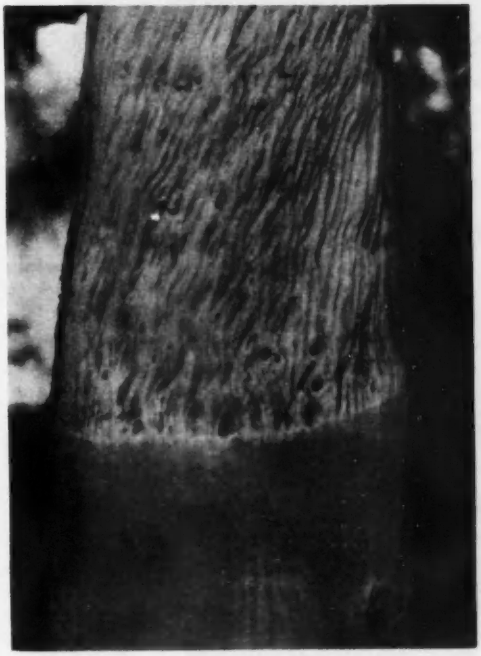

Figure 1. Marsh grapefruit on sweet orange stock, showing portion of trunk at union with bark removed. The grapefruit wood shows extensive pitting, whereas the sweet orange wood is normal.

Figure 2. A tree of Marsh grapefruit on Rough lemon stock in advanced stage of decline showing extensive die-back, sparse foliage, and small fruit. Other trees in the same orchard, although infected with the same stem-pitting virus, may appear in good condition and produce good crops.

Figure 3. Natal tight skin naartjie on sweet orange stock, showing extensive die-back of branches. Trees on Rough lemon stock show a similar decline.

fruit and accompanied by symptoms of wood-pitting and secondary decline has been observed in experimental plantings of the citron, Tahiti lime, and the West Indian lime.

Tangerines. Budded trees of the Natal tight skin naartjie (variety of tangerine) on Rough lemon stocks have a commercial life of no more than 10 to 12 years. The decline follows much the same pattern as that in grapefruit, but die-back of the branches is more extensive and often causes the death of the tree (Figure 3). On the other hand there are many examples to be found of seedling trees on their own roots of the same variety that are still productive after 30 to 40 years.

Virus infection occurs in both budded and seedling trees. Although the exact cause of the decline in budded trees has not been established it is probably associated with virus infection. The composite nature of budded trees may make them more sensitive to injury as is the case with certain scion-stock combinations in their behavior to tristeza virus.

Lemons. Eureka lemons on Rough lemon stock also tend to decline prematurely. Virus infection is also general in trees of this species whether they are in good shape or declining. This could be a further example of the harmful effects that eventually overtake an aging tree in spite of good tolerance of the tree when young.

Rootstocks. In field experiments some species of citrus have been unsatisfactory as rootstocks, and scions of commercial varieties have either failed to grow on them or the resulting trees have been poor and unthrifty. It is now established that some of these failures are primarily caused by virus infection. The best example is the sour orange, to which reference has already been made.

When the buds of orchard trees of a sweet orange or tangerine are grafted on sour stocks they either fail to grow, or growth is very poor. Grapefruit scions make a slightly better performance but not sufficiently to develop a productive tree. But some varieties of lemons (Eureka and Lisbon) grow well on sour stocks and develop into sizeable trees in spite of the infection carried over from the parent trees. The simple explanation for the variation in the performance of different species of scions on sour roots is that the infection carried in the scions differs qualitatively; and that the sour orange is most sensitive to the infection that occurs naturally in sweet oranges and tangerines and least sensitive to the one in lemons. Further reference to this follows later.

Three more examples of root stocks which have been failures because of virus infection are the sweet lime, sweet rough lemon, and *Poncirus trifoliata.*

Nature of Virus Infection Prevalent in South African Citrus

In Australia, Fraser (2) demonstrated a consistent qualitative difference in the virus content of different species of citrus in orchards where tristeza occurs. She used as test plants seedlings on their own roots of Eureka lemon, sour orange, and grapefruit, and transmitted infections to them by grafting. The virus complex occurring naturally in trees of various varieties of sweet orange and mandarin caused severe stunting and yellowing of the test plants. But the virus in trees of Eureka lemon, sour orange or grapefruit caused either no leaf symptoms or just occasional vein fleckings in the spring growth, and no apparent stunting. These results have been fully confirmed in South Africa (Figure 4), where the position appears to be much the same as in Australia.

The more virulent effect of the virus

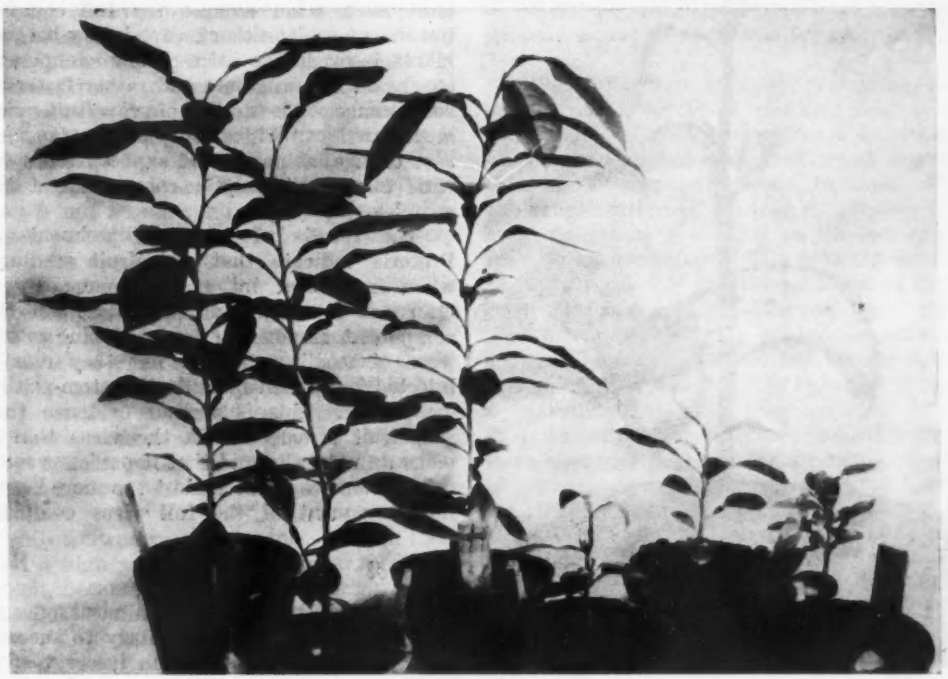

Figure 4. Reaction of sour orange seedlings to virus infection. The three seedlings on the left are infected with virus from grapefruit trees, the three on the right from sweet orange trees.

complex out of sweet oranges and mandarins on the test seedlings Fraser ascribed to a special component which she called seedling-yellows. This component she regarded as distinct from the tristeza-stem-pitting complex but added that in nature it had not yet been found unaccompanied by the tristeza virus. But McClean and van der Plank (5) interpreted the results differently and suggested that the tristeza virus complex has two components: a stem-pitting component, able on its own to cause stem-pitting in grapefruit, and a seedling yellows component that by definition must also be present to cause severe stunting and yellowing of seedlings of Eureka lemon, sour orange, or grapefruit (Figure 5).

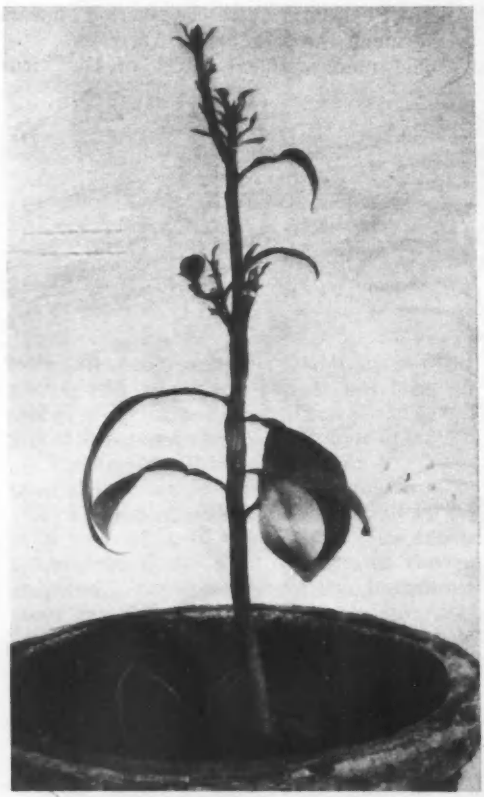

Figure 5. Sour orange seedlings, showing the typical "seedling-yellows" reaction following inoculation from a sweet orange.

McClean and van der Plank pointed out that the concept of tristeza virus as a complex that is ordinarily taken up as a whole by some trees in the orchard, like sweet oranges or mandarins, but only in part by others, like sour oranges, Eureka lemons or grapefruit, explains the behavior of different species of citrus when they are exposed to tristeza infection. Sour orange and Eureka lemon trees escape serious injury because they take up only a part of the complex that they can tolerate and remain free from the seedling yellows component. For this reason they are equally safe on their own roots or as scions on any rootstocks. In other words they are safe when the infection can enter the tree only by way of the sour orange or the Eureka lemon. Sweet oranges and mandarins are safe enough on their own roots because they are tolerant of the whole virus complex, but suffer on rootstocks like sour orange or grapefruit that are intolerant of seedling yellows after the complex has passed down across the graft union. Grapefruit as a scion escapes the full complex but does not altogether escape injury because it reacts with the stem-pitting component slowly on its own roots and rather faster on sour orange. The decline of grapefruit scions is slower than the decline of sweet orange on sour orange, as one would expect from a decline caused by only a component of the complex.

The results of recent experiments in Pretoria indicate that grapefruit seedlings when inoculated by grafts from a sweet orange or mandarin source tend to lose the component responsible for producing symptoms of seedling yellows, but they remain infected permanently with the stem-pitting component. This is further evidence that grapefruit is selective in the virus that it picks up naturally and that it possesses some defensive mechanism against the more harmful component of the full virus complex.

Control

The eradication of tristeza virus once it has gained a foothold is unlikely to succeed in any country possessing an insect vector. Moreover, such factors as spread of infection by aphides, the perpetuation of infection in the clonal progeny of infected parents,

and the fact that the host is a tree with a semi-permanent place in the field mean that the infection will ultimately become general in citrus trees.

In countries where tristeza virus has existed for many years and where sweet oranges have had to grow up with the infection, tristeza disease, as we know it from South America, has never been of economic importance. This is because the species used as rootstocks were ones on which the sweet orange grew well and which have been shown since to possess good tolerance.

But a tolerant stock is not the complete answer to the problem as a whole, because some species are sensitive to the infection they acquire naturally, and decline prematurely whether they are grown on their own roots or on the roots of tolerant species. The best example of this is the West Indian lime in which infection by tristeza virus causes a rapid die-back of seedling trees on their own roots. The disease has resulted in the virtual extinction of a small lime industry in the Gold Coast. Martyn (6) states " that attempts at rehabilitation of the lime industry by the use of rough lemon stock have not proved wholly successful due to suckering of the stocks and comparative rapid reappearance of die-back contracted from the neighboring sources of infection. " It is now concluded in the Gold Coast that the lime - Rough lemon combination is not an answer to the problem unless one is prepared to replace infected trees every six years or so.

Grapefruit is another species that is sensitive but much less so than the West Indian lime. It also tends to decline prematurely even when budded on a tolerant stock.

The main problem for the future is how long existing citrus clones, including those of sweet orange, will continue to be productive under the influence of virus infection. The solution probably lies in the nucellar seedling.

Most citrus species produce through their seed a high proportion of nucellar seedlings, which, because of their asexual origin in the nucellus, conform closely to the parent type. They possess juvenile vigor and initially are free of infections that may be present in the parent. Work in California by Frost and others indicates that the nucellar seedling provides a means of re-establishing commercial varieties when they become weakened by virus disease or old age. Objections to its immediate use as an orchard tree are raised on the grounds of thorniness, slowness in coming into bearing, and the uncertainty of its ultimate performance from a commercial standpoint. But experience has shown in California and elsewhere that nucellar seedlings produce vigorous trees which in many cases bear good crops of quality fruit.

In South Africa the problem of early decline in the Natal tight skin naartjie when budded on Rough lemon has been largely solved by growing this variety as seedling trees on their own roots. The proper selection of uniform, vigorous seedlings insures an orchard of uniform trees. Preliminary observations from a small experimental planting of grapefruit seedlings suggest that the same procedure may be successful for grapefruit as well.

When a tree is formed by growing one species on the roots of another, it may be made more vulnerable to infection, depending on the two species and their relative position in the composite tree. In such cases the simplification of the tree by growing the scion species as a seedling on its own roots may be an advantage. The better behavior of Natal tight skin naartjie seedlings on their own roots as compared with trees budded on Rough lemon stock may be due not only to juvenile vigor but also to the former being less vulnerable to the type of infection picked up naturally.

Mild strains of virus are reported from most countries. They offer a possible means of protecting sensitive trees against the harmful effects of the full virus complex. But it is still a matter for experiment whether this method of immunization has practical possibilities.

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Symposium on Tristeza Disease of Citrus

This symposium, which reviews the present situation of the dangerous tristeza disease in various citrus-growing regions of the world, includes three additional papers which will be published in the next issue of the FAO Plant Protection Bulletin:

Present status of the tristeza disease of citrus in South America, by A.S. Costa

The threat of tristeza disease in the Mediterranean Basin, by Kurt Mendel

The tropical citrus aphid, by J.P. Doncaster and J.F. Eastop.

News and Notes

EPPO Meeting on Tristeza and Xyloporosis of Citrus

A Working Party on Tristeza and Xyloporosis will be organized by the European and Mediterranean Plant Protection Organisation (EPPO) in Portici, Italy, 14-16 May 1956. The problem of keeping the tristeza disease out of Europe and especially of the Mediterranean area was discussed at the EPPO Mediterranean Plant Protection Conference held in Sicily in 1952 and governments were advised to undertake grafting tests before distributing introduced seeds or stocks to growers. Recent evidence, however, indicates that the tristeza virus is present already in the Mediterranean area in imported citrus varieties. The xyloporosis disease is probably the most destructive citrus disease in Israel but its known distribution in the Mediterranean area appears to be still limited.

The forthcoming Working Party, in which experts from EPPO member countries interested in citrus cultivation will participate, is being convened to discuss measures required to prevent any further spread of these two diseases and make recommendation accordingly to the governments concerned.

International Congress of Mediterranean Citrus Growers

The 4th International Congress of Mediterranean Citrus Growers, organized by the Government of Israel and the Citrus Control and Marketing Boards of Israel, will take place in Tel-Aviv, 20-27 May 1956. The Congress will study problems relative to citrus production in the Mediterranean, from the agricultural, technical, economic, commercial and industrial viewpoints, for the purpose of facilitating relations between the various activities concerning citrus production and its commerce, and of accepting joint solutions to the problems common to all.

The Congress will be composed of three sections: technical, commercial and industrial. In the technical sections, the following subjects will be covered: virus diseases (description, spreading and control); new aspects of pest control; new insecticides and fungicides; deficiency diseases; pest control. Excursions will be arranged before and after the Congress.

Roma - Tip. del Senato del dott. Giovanni Bardi